Hacking the Natural Habitat: An in-the-wild study of smart homes, their development, and the people who live in them

Mennicken, Sarah ; Huang, Elaine May

Abstract: Commercial home automation systems are becoming increasingly common, affording the opportunity to study technology-augmented homes in real world contexts. In order to understand how these technologies are being integrated into homes and their effects on inhabitants, we conducted a qualitative study involving smart home professionals who provide such technology, people currently in the process of planning or building smart homes, and people currently living in smart homes. We identified motivations for bringing smart technology into homes, and the phases involved in making a home smart. We also explored the varied roles of the smart home inhabitants that emerged during these phases, and several of the challenges and benefits that arise while living in a smart home. Based on these findings we propose open areas and new directions for smart home research.

DOI: https://doi.org/10.1007/978-3-642-31205-2_10

Hacking the Natural Habitat: An in-the-wild study of smart homes, their development, and the people who live in them

Sarah Mennicken, Elaine M. Huang

Zurich People and Computing Lab, Department of Informatics, University of Zurich, Zurich, Switzerland
{mennicken, huang}@ifi.uzh.ch

Abstract. Commercial home automation systems are becoming increasingly common, affording the opportunity to study technology-augmented homes in real world contexts. In order to understand how these technologies are being integrated into homes and their effects on inhabitants, we conducted a qualitative study involving smart home professionals who provide such technology, people currently in the process of planning or building smart homes, and people currently living in smart homes. We identified motivations for bringing smart technology into homes, and the phases involved in making a home smart. We also explored the varied roles of the smart home inhabitants that emerged during these phases, and several of the challenges and benefits that arise while living in a smart home. Based on these findings we propose open areas and new directions for smart home research.

Keywords: Home automation, smart homes, domestic technologies

1 Introduction

Smart and automated home technologies have been an important focus of ubiquitous computing research since the inception of the field. The research community continues to push the boundaries of novel sensing and applications in the home to support various tasks and processes, such as health and wellness, cooking, aging, and communication. In the meantime, commercial systems that support more basic tasks of home automation have been developed, and their adoption and use offer a picture of today's "smart homes" in contrast with the vision represented in most pervasive computing research on smart homes. Although automated home technology has yet to be widely adopted, it is beginning to penetrate beyond an audience of extremely wealthy or extremely technically-savvy homeowners. Furthermore, recent studies by ABI Research indicate the growing ubiquity of home automation, finding that nearly

1.1 million home automation systems will be purchased in North America in 2012[1], and that revenue from such systems will exceed $11.8 billion in 2015[2].

The increased interest in and use of "smart" home automation present a unique opportunity to look at how early adopters of these technologies are integrating them into their homes and lives. An understanding of how home automation is adopted and its impact on people will be valuable in providing insight about how future smart home technology should be designed to fit their needs and expectations. The growing population of people who have opted to instrument their homes with smart home technology provides us with the opportunity to learn about motivations for creating a smart home, the "real-world" process of developing a smart home, and the effects of smart homes on the everyday lives of their inhabitants in a naturalistic, non-experimental, non-laboratory context.

In this paper we report on a qualitative study of three key groups of stakeholders in the current landscape of commercial smart home technology: 1) inhabitants of homes equipped with automation technology, 2) people in the process of planning or building automated homes, and 3) providers of existing commercial solutions for home automation. Our objective was to understand how a smart home currently develops, from the initial idea to instrument the home to the emergent uses of its technology by household members. Our focus was on "smart homes" that made use of either commercial or custom solutions for home automation that are integrated into the home's infrastructure, because such households were reasonably accessible to us, and because we believe these to be some of the important predecessors to the types of innovative home technology on which the research community is focusing.

This work offers several key contributions to the field of pervasive computing, namely the articulation of several stages involved in developing a smart home, challenges that arise in the various stages, and people's motivations for wanting a "smart home", such as the aspiration of modernity, joy of hacking, and experienced benefits that whet one's appetite for more. We also explore the roles that emerge in this process and how each of them influences the development and use of the technology. In addition to these findings, this research poses several other novel contributions, such as providing a holistic understanding of the development of smart homes synthesized from the perspectives of multiple types of stakeholders through naturalistic experiences, and the identification of open areas for new smart home research to support a broader process and variety of roles than have typically been considered.

2 Related Work

Domestic technology and smart homes have been a topic of research for several decades. As such, there is an extensive body of existing research on smart homes and domestic environments which would be too large to cover exhaustively in this paper.

[1] http://www.abiresearch.com/press/1555-North+America+to+See+Nearly+1.1+Million+Managed+Home+Automation+ Systems+Shipped+in+2012

[2] http://www.abiresearch.com/press/1633-Home+Automation+Systems+Reve/nue+to+Approach+$12+Billion+Worldwide+in+2015

We therefore focus our treatment of related work on the specific areas of smart home research that are most directly relevant to the work that we present in this paper.

Research on smart homes has been carried out at various levels of abstraction: Taylor et al. explored the understanding of the general notion of "smart" in this context [29], emphasizing the importance of the actual interaction as an aspect of intelligence. Randall provides a differentiation of several kinds of smart homes that are able to provide smart functionality beyond the accumulation of smart appliances [24]. In this paper we add to the understanding of what the notion of "smart" actually means to people living in smart homes. Crabtree and Rodden highlighted the need to consider specifics of domestic routines [10] by exploring coordination and communication in the home in order to inform design of home technology. In our research we build upon this work by considering such routines within the larger context of the smart home development process.

Other research has been interested in a high-level understanding of people's general intentions regarding ambient intelligence appliances: Allouch and Van Dijk quantitatively investigated prospective users' intentions to get such appliances, based on an acceptance model for anticipated adoption and outcome expectancies [2]. The respondents in their study showed a low degree of intention to adopt those appliances.

One key area of related work has involved the identification of user requirements to provide design guidelines for the domestic environment [11, 25]. For example, Bell and Kaye considered the notion of focusing on the experience of, rather than efficiency with, kitchen technologies [4]. Seminal work by Edwards and Grinter provides an overview about technical, social, and pragmatic challenges that arise in homes equipped with ubiquitous technologies [13]. While this understanding of users' needs might offer hints about the motivations for advanced technology in the home, it does not directly address the concrete reasons for integrating it into one's home in the first place.

Other research has focused on understanding the meaning of space within the home. Elliot et al. highlighted the importance of the diversity of locations in the home [14], and Aipperspach et al. argue that losing heterogeneity of space, technology, and time in the home results in a less fulfilling experience [1].

Some home research has looked specifically at roles within the home in relation to technology. There has been other work in more specific fields on domestic routines and evolving roles of users, such as for example in health applications and Ambient Assisted Living [3, 32], stressing the importance of user-centered and careful integration of (medical) technology in the domestic environment. There has also been work on how people configure their home networks [9] and the different roles householders engage in based on their degree of active involvement [23]. Our work complements some of these findings by considering similar emerging patterns in relation to smart home technology.

Other work has considered people's relationships with home technologies [16], and ways to simplify end-user configuration of ubiquitous home computing technologies [18, 26, 31]. Earlier research on end-user programming in the domestic context explored which appliances are programmed and how [27, 28], to inform better design for end users. More recently, research has been conducted on ways to facilitate the broader adoption of home automation, by providing better means to fit home

automation to the inhabitants' needs. Dixon et al. [12] argue for empowering end users by providing home-wide operating system.

In order to study and explore the interaction between people and smart home technology, several universities and research institutions have built smart home laboratories that allow for more ecologically valid, situated installations of home technology. These laboratories have allowed researchers to explore many aspects of home technology, from the challenges of realizing systems to the experience of living with them. Two notable projects amongst others have been the Aware Home [21] and MIT's house_n [19]. These projects provide an interesting complement to our research, as they consider future home technologies in a living laboratory setting that allow for controlled observation. Because home automation technologies have yet to be widely adopted by home owners, few studies have been conducted thus far in technology-equipped, "in the wild" homes. In one example of such a study, Woodruff et al. [33] conducted a home-tour-based study, focusing on a specific user group of Orthodox Jewish families. Brush et al. [5] also conducted a study of automated homes which provided insights about barriers and opportunities for a more general user group of smart home users. In the our study add to this knowledge and expand the scope of research on home automation in-the-wild by considering the broader process involved in planning, building, and living with smart homes.

3 Study Method

We undertook a qualitative study involving three groups of participants to learn about the process of creating "smart homes", beginning in the spring of 2011. Our data was collected in two phases, the first of which focused on smart home professionals, and the second of which focused on inhabitants of smart homes and people in the process of building smart homes. This study design differs from previous studies on "smart homes" in that we strived to extend our understanding to the whole process of making a home "smart" including the planning stage of building or renovating a home. Our study comprised semi-structured interviews with a total of 22 participants (10 inhabitants in 7 households living in smart homes, 5 people in 3 households who were in the process of planning or building smart homes, and 7 professionals) and home tours of six of the inhabitants' homes. All but one of the inhabitant/planned inhabitant interviews were done in person, and all but two took place in the participants' homes. Interviews with smart-home professionals took place over the phone or on Skype (audio only). All interviews were conducted in German (the native language of the participant) except for one that was conducted in English (the common language of the participant and interviewer). All interviews were audio-recorded, and photographs were taken during home tours.

To analyze the data, we used a grounded theory-based affinity analysis [6]. We first transcribed approximately 1200 data items from the interview recordings, and translated them into English to facilitate collaborative data analysis within our international research group. The affinity diagramming process yielded a broad set of findings; this paper relates only a partial subset of these findings, namely those most related to the process of developing a smart home.

4 Participants and Households

Our motivation for studying smart home professionals was to learn how the commercial processes for smart home technology currently work. We wanted to learn whether professionals get feedback from their clients, what kind, and how they integrate it in order to develop new products, which trends they follow, and also to get an initial idea about their clients and the difficulties they face. In the first phase of our data collection we recruited seven professionals (6 male and 1 female, referred to by participant numbers prefixed **P** throughout this paper) from Germany, Switzerland, and Austria by contacting various companies via email. Four were system integrators for distributed bus system solutions, which provide functionality by connecting individually smart components (in this study the KNX[3] standard or proprietary Crestron[4] solutions); their job was to provide consulting for specific distributed bus system solutions and create custom solutions for clients. Two were CEOs of companies providing their own central solutions in which the functionality is handled by a central unit. One professional was employed at a large company which offers components for home automation. They did not receive any incentive beyond the opportunity to be acknowledged in this work. Interviews lasted between one and two hours and were audio recorded.

The second phase of data collection involved interviews with German and Swiss participants who are either current inhabitants of smart homes (***inhabitants***, referred to by participant numbers prefixed **I**) or in the process of planning smart homes (***planners***, prefixed **PL**). We define planners to be people who were in the process of building a home and researching home automation technology to be installed, either on their own or with the assistance of a company providing home automation technology. These interviews focused on the appeal of home automation, participants' understanding of smart homes, and the effects of the technology that they perceive or expect. In the interviews with planners we focused on their experiences with the planning and their expectations of the technology. For inhabitants we focused on the perceived effects of and experiences with the technology. Interviews with planners lasted between 45 and 90 minutes. Interviews in inhabitants' homes (all but I6, who was interviewed over the phone) lasted between two and a half and four hours, including home tours. Participants in this phase were recruited on online forums and social network groups about home building and home automation, and on two system providers' online forums. Additionally, three participants were recruited through references from the professionals interviewed. The participants received gift vouchers of CHF 15 (planners) and CHF 25 (inhabitants). It should be noted that the study participants do not constitute a representative sample of households with smart or automated home technology. In addition to the geographic restrictions of our study, our recruiting method may also place restrictions on the generalizability of our findings. For example, the fact that we recruited smart home inhabitants primarily through online forums may skew our population towards people who rely on and participate in online communities for smart home information and support.

[3] http://www.knx.org
[4] http://www.crestron.com

We attempted to recruit participants with a variety of technical expertise. Three of the households had little technical background represented; in the remaining six households the male adult participants had a background in information technology or electrical engineering while the females did not. Our participants came from a variety of occupational backgrounds with a large number coming from tech-related jobs. Occupations included a patent attorney, a banker, two software engineers, a CEO of a software company, two teachers, a tax accountant, a technician for building security, one unspecified part time job, a housewife, an art collector, and a project manager for usability. The participants' living situations are outlined in Table 1. Inhabitants had lived in automated homes for at least three years except for I1 and I6 who had lived in their new flats for six months. I1, I2 and I3 live in their homes together with children. All adult male household members were involved in the programming/configuring in their homes except for I7h, who outsourced or delegated all of the home automation tasks. In all cases, the introduction of automated home technology coincided with a major home renovation or a move into a newly built home, since installing a distributed bus system with independent components requires fundamental renovations unless the home was built with channels for the necessary additional wiring. Most households had a bus system installed in their homes or in combination with a central solution, except for I1, who used only a central solution for his home automation. The visited homes were all owned by the participants, and included two flats, three semi-detached homes, and two larger single-family homes. Because we recruited multiple participants from the same online communities in some cases, we have opted not to associate participants with their occupations as doing so may make them identifiable to other study participants who participate in the same forums. Instead, we provide context about participants' backgrounds when relating their perspectives or experiences as necessary.

Table 1. Participants of the second phase of our study (I(nhabitants), PL(anner), w(ife), h(usband)).

Household	Participant (gender, age)	Living situation
I1	I1 (male, early 40s)	Flat, with girlfriend and two kids (15, 17)
I2	I2w (female, late 30s)	Semi-detached home, with two kids (10, 11)
	I2h (male, late 30s)	
I3	I3w (female, 35)	Semi-detached home, with two kids (7, 11)
	I3h (male, 37)	
I4	I4 (male, 51)	Single family home, with girlfriend
I5	I5 (female, 57)	Single family home, with husband
I6	I6 (male, 33)	Flat, with girlfriend
I7	I7w (female, 61)	Semi-detached home
	I7h (male, 61)	
PL1	PL1 (male, 38)	With girlfriend
PL2	PL2w (female, early 40s)	With three kids (5, 7, 9)
	PL2h (male, mid 40s)	
PL3	PL3w (female, late 30s)	
	PL3h (male, early 40s)	

As mentioned earlier, we limited the scope of smart homes to homes that made use of either commercial or custom solutions for home automation that are integrated into the home's infrastructure. All home automation systems included at least automated heating, light, or shades controlled by sensors or time settings. Some households had additional "smart" technologies (such as vacuum-cleaning robots or an independent automatic watering system) independent of the general infrastructure for home control. Every household had advanced climate control and/or feedback. Five households had remote access to some information about the home. Three households had functionalities based on presence detection. Five of the seven households had programmable "scenarios", meaning they were able to assign the execution of several tasks or functions to a dedicated switch or a button on an input panel.

5 The Understandings of "Smart"

Although we approached this study with a particular scope on "smart" homes, we also wanted to understand what our participants considered to be smart, clever, or intelligent about their homes without imposing our definition on them. We asked participants to share their ideas with us, inquiring about what they consider "smart", "clever", or "intelligent" in their homes in general without focusing explicitly on technical aspects of the home. We asked professionals the same question to gain insights into potential mismatches. It should be noted that participants generally did not refer to their homes as "smart homes"; rather, they described certain aspects, features, or functionalities of their homes as smart.

Smart is what fits my routines and avoids unnecessary work. A key theme that emerged was that participants considered "smart" to be that which fits, speeds up, or improves their routines while avoiding unnecessary work (I3h, I4, P7, PL3h). This understanding of "smart" is related to Brush et al.'s finding that one of inhabitants' favorite aspects of home automation is "convenience"[5], our finding does not specifically address home automation technologies but what is considered "smart" in a more general context. This includes also non-technological aspects, such as an appropriate spatial layout of the home (PL3h, PL3w, I3h). I3h*: "The door outside [makes the basement accessible from the garden] so you don't have to walk through the living room with rubber boots on. Absolutely non-technical, but smart in relation to our routines."* Another aspect of "smartness" was that technology, no matter how powerful, needs to fit into everyday life, as expressed by I2w: *"At first I was considering the one that wet-cleans [note: iRobot's Scooba®] because I thought it would be more useful on tile; but it doesn't have a docking station where it can recharge, so I would have to connect it every time, and, well, that's stupid."* In order to support routines in a "smart" fashion, participants felt that a home would need to be equipped with an extensive range of functionalities. They felt a home that was not fully equipped for automation or prepared for future additions of such equipment was restricted in terms of its functionality and potential benefit. (I3h, I6) I3h*: "It doesn't make a lot of sense in home automation to install one part conventionally and another part automated. It always depends on what you want, but a really intelligent or*

'smart' home where you can represent scenarios… You really limit the whole house if you don't [fully equip it with the requirements for automation]."

It's not smart if I can do it better. Participants without technical backgrounds or a strong interest in technology reported they did not see a benefit to automation if they could still perform the same task faster or better manually (I1, I2w, I3w, PL3w). Merely being convenient was not sufficient for automation to be considered "smart". E.g., I3w*: "You [addressing her husband] always wanted to [automate] the shades over there, but I felt: 'No, I don't need that,' because I'd argue that I can still do it faster myself."* The stakeholders, including professionals, inhabitants, and planners, all agreed that technology itself is not smart, but applications of technology could be smart. They felt that adding the functionality and mapping functions to the different components was what resulted in instances of intelligence (I3h, I4, PL3w, P4, P6), as stated by P4: *"It actually only becomes smart if you give the thing its function."*

6 Motivations for Home Automation

One of our main goals was to explore people's reasons and motivations for equipping a home with substantial additional technology which requires investment and architectural planning. Our interviews revealed several key factors; households often cited several of them as motivations.

Modern homes are smart homes. One primary motivation people expressed in our study for getting smart homes was that they felt that a modern home should have the highly advanced technological infrastructure, even when their ideas about such infrastructure were vague. Although people in our study generally did not perceive home automation as having a major impact on their lives, they felt that one ought to consider the latest technology when building a new home (PL1, I5, P3, P7). This was the primary motivation for the two participants who outsourced the installation and programming of their homes, for example I5: *"And we also wanted a modern home; [therefore we wanted one] with technology."* We also discovered a similar attitude among planners, for example PL1, who stated: *"It's nothing you 100% need, but we're in 2011 and normal light switches like those from 40 years ago… it's always the same, nothing new."* This concurs with professionals' impressions of their clients' motivations, e.g, as expressed by P7: *"I never would have thought that they'd want such a solution [home automation], because they haven't even had a real internet connection until now… but it was pretty clear to them: they want a modern house."*

Experiencing benefits increases interest in upgrades. We found motivation to equip the home was sometimes self-perpetuating among the participants. Just as the act of eating can sometimes stimulate the appetite, participants thought more about what else they might automate, once they felt comfortable and trusted the automated functions in their homes (I1, I2h, I6, PL2, P4, P7). *I1: "At the beginning the control was limited to shutter control and to two lights and then I noticed: actually there are a couple of functions that would be interesting, e.g. that scene control, so that I can*

express with one single button click: 'I want to watch TV here' and the whole environment adapts itself to it." Adding technology and functionality in the home seemed to have the effect of feeding the interest in building on such technologies.

Hacking the home is a hobby. Participants with a technical background mentioned a strong general interest in novel technologies and smart-home functionalities. They likened investing time and money in these technologies to investing in any other hobby (PL2h, I1, I2h, I4, I6). As I2h put it: *"Instead of having a model railway I have this home."* Some not only spent money and substantial free time configuring their homes and adding new functionalities, but also engaged in related online communities, shared experiences, participated in interest group meetings, or attended talks on the subject. They mentioned that they enjoy doing things themselves and that their smart home "hobby projects" provide them with a sense of achievement (I1, I3h, I6). I1 said: "*I enjoy doing stuff myself. I prefer that, actually. Not necessarily because of the possibility of saving money, but just to find out: can I do it or can't I?"*

Smart homes save energy. Another reason for investing in advanced building technologies that our participants reported was the desire to save energy (PL1, I3h, I4) I4: *"Saving energy in general is a reason why I decided to invest massively in insulation and so it's actually logical that you do it right and so, you need to think about electricity [consumption]."* Some participants explicitly mentioned the desire to save money and were concerned about whether the investment would pay off (PL2, P5, P7) PL2: *"Energy efficiency is one of our interests and you can discuss if it covers the cost of investment or if you get it back, but on the other hand you invest a lot of money in a home in general."* Although we will not focus on this specific motivation in the analysis presented in this paper, it was mentioned by several participants and will be considered in greater depth in future analyses.

7 Phases of Growing a Smart Home

We derived four key phases of developing a smart home based on our participants' reports of their experiences (see Figure 1) so as to provide a structured framework to present our results. Although we present these phases as a linear sequence, it should also be noted that certain events, such as a software update or addition of a new component (e.g. new sensors) can trigger the return to a previous stage in the cycle.

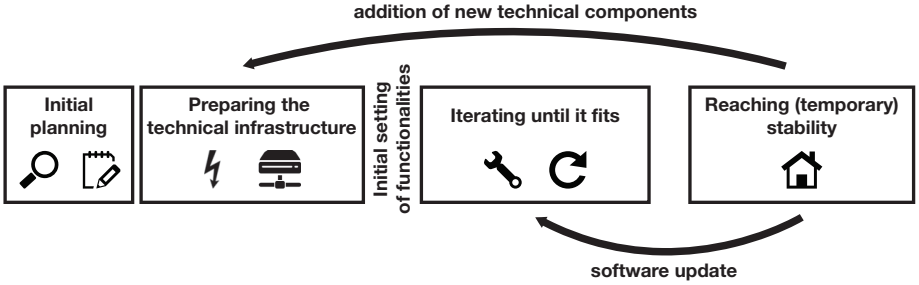

Fig. 1. Different stages of creating a "smart home".

Initial planning. All inhabitants and planners (except for I2) equipped their homes with automation technologies when either building a new home or performing major renovations. This agrees with previous findings [5], and was confirmed as typical by the professionals we interviewed. In this phase home technology drivers talk to the electrician, and conduct research either online or by talking to professionals. Usually with the assistance of an electrician, architect, or consultant, but in some cases acting alone, they create and iterate upon complex technical installation plans. The duration of this phase varies; professionals stated that some people begin planning the electrical installation and home automation technologies even before purchasing the property, while other participants reported starting with their planning of the automation components just a few weeks before the actual installation in their homes. In some cases the planning phase was limited to the planning of the technical infrastructure for the home, while in other cases it extended to determining the eventual functionality and configuration of the home automation systems. Many participants spent a significant amount of time learning about specifics and the range of available technologies. In one case a participant planned out light, power supplies, and motion sensors along with the positions of the furniture in order to place components optimally and allow for extensive building automation (see Figure 2).

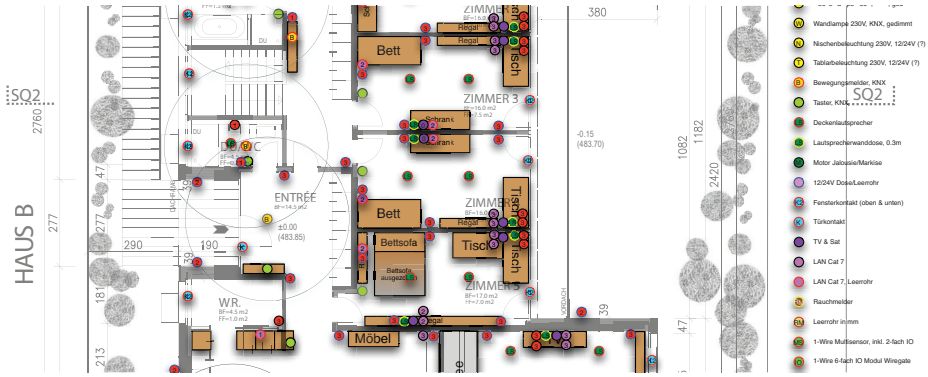

Fig. 2. Participant's document to plan furniture placement, lighting, power sockets, and home automation components. E.g. the circles on the left hand side highlight the areas covered by the motion sensors.

Preparing the technical infrastructure. After the needed infrastructure was planned out, electricians or, in the case of two households, inhabitants with a professional background in electrical engineering installed the technical components such as actuators, sensors, switches, and cables for bus systems, etc. As explained by P7, this was not only for reasons of difficulty but also for safety*: "The installation will always be done by electricians. For safety reasons … it will always be better off with [professionals]."* When the technical components were installed, an initial configuration of the system was done. The duration of this phase depended on the size of the building and complexity of the automation technologies.

Iterating until it fits. Following the initial setup was a period of adjustment during which participants learned how the assigned functions fit with their lives and what did

not work for them (I2h, I3h, I5, P5). This resulted in iterations of the system configuration. The necessity of iteration has also been reported by Brush et al. [5]. Several participants described this period as frustrating and chaotic, as reported by I3h*: "For me it's like an ongoing construction site. So it's normal that it's nonsense."* This phase often started with frequent changes to the configuration. Changes grew less frequent and as the functions, assignments, and visualizations gradually became better suited to the inhabitants' routines. I1 stated, *"In the beginning, until the shutters worked properly, until the light worked, I actually modified it on a daily basis and adjusted it and tried to get it running. Now that I have the basic functionality [working], the time [between modifications] is getting longer."* The changes became less substantial, indicating a shift from major adjustments to fine tuning, as described by I2h*: "The current visualization is the third version that I created. The first and second ones differed a lot, the second and third not so much."*

Reaching (temporary) stability. After the iteration, a period of stability was reached during which the active configuration of functionality stopped (I5, I6, P5). As I6 stated: "*But [the remapping] stopped. From the beginning until I assigned the final setting [...] it was a little chaotic."* This period of stability did not necessarily imply a state of satisfaction with the technology or optimized functionality. Particularly in households with enthusiasts who considered home automation a hobby, this state was temporary because they were still planning new functions or upgrades during these periods. In such cases, the homes soon entered a new cycle of iteration.

8 Roles of Inhabitants

One of the themes that arose repeatedly in our interviews was the variation of roles that household members assumed in relation to their smart homes; these roles appeared to apply to both inhabitants and planners, and reflected how people engaged in the planning, iteration, and use of smart home technology. The roles we describe in the following sections map roughly to the roles introduced by Poole et al. [23] in the home networking context and applied by Brush et al. [5] in the home automation context. We extend upon previous categorizations, deepening the understanding by providing specific characteristics and including the roles in the context of planning a "smart home".

Several participants had a strong technical background, in some cases on account of having done a degree or apprenticeship in a technical field. Such participants engaged actively in the planning phase and assumed primary responsibility for the technology once it was installed. We identified this group of people as **home technology drivers.** They showed a strong interest in equipping their homes with home automation technology and conducted research on the subject in their spare time, acquiring technology for their home and trying it out (I1, I2h, I3h, I4, I6, PL1, PL2h). Three participants engaged in home automation communities by contributing to online forums or attending meetings or talks (I3h, I4, PL2h). They often reported having many ideas for further technology additions to their homes as hobby projects (I1, I3h, I6, PL2h). I1 spoke of needing to manage these ideas, stating *"I have so*

many whims in my head, so I have to set priorities." In our study we identified PL1, PL2h, I1, I2h, I3h, I4 and I6 as home technology drivers. They assume technical responsibility for systems while household members turn to them for system support (I1, I2w, I3w, I4), as described by I2w: *"If something turns on or off or whatever, I simply notify him."*

In two of the households without members with technical backgrounds, some household members still assumed primary responsibility for the technology (I5, I7h, I7w). Although these **home technology responsibles** generally did not engage directly with the technology, they were the ones who were motivated to have the technology installed, and took responsibility for having the technology repaired or adjusted by professionals as needed. In contrast with the role of "assisters" introduced by Poole et al. [23], home technology responsibles in our study did not assist others in their household by taking care of issues or extensions of their home automation.

Most other adult members of the households fell into the category of **passive users**. These participants (PL2w, PL3w, Pl3h, I2w, I3w) did not actively engage in home automation research, planning, configuration, or maintenance, but had some familiarity with the systems and controls through use. They generally left the details of planning and maintenance to the home technology drivers. E.g., PL1 described the decision-making dynamic with his wife regarding the technology planning: *"For those things my wife says: you can decide and then we will see."* In our study several passive users (I2w, I3w, PL2w) were the wives of (male) home technology drivers, though our sample is not large enough to say whether these gender roles generalize to smart-home households in general. Passive users made use of the automation but were generally not interested in adding to its features or actively using it to its full extent, as indicated by I2h and I2w: *Interviewer: "Can you access your home with your phone?" I2w: "Not with mine." I2h: "Yes, you can." I2w: "Yes, but right now I couldn't, because it's not on there." I2h: "Technically you could, but you were never interested in that, in wanting that."* In many cases, however, passive users spend more time at home than the home technology drivers, which made them astute evaluators of the technology (I2w, I3h, I3w, I4). I3w:, *"Technology is mainly his topic. I wait for what he shows me and then I say 'that's good' or 'that's not good.'"*

We did not interview further inhabitants or users directly, but participants referred to other groups of people who were affected by the technology, namely children and guests. Some participants (I1, I2, I3, P2, P7) noted how **children** generally become accustomed to technology easily, as illustrated by an anecdote from I3 in which they talked about how their daughter attempted to turn on the lights by waving her arms while on vacation. I1 talked about how their children were comfortable with the technology and enjoyed playing with the shades using the tablet to control them.

People in our study also expressed the desire to make their homes accessible to **guests** (I1, I2h, I4, I6) but stated that unfamiliar home technology can pose problems for visitors. They pointed out elderly visitors in particular as having potential difficulties with smart technologies*: "If my mother had to start with that [using a touch panel to turn on the light]… well, she can't even remember where she was an hour ago; but she grew up knowing that you have to press [a physical switch]."* As first time users of the technology, guests may be afraid of breaking something in the home, as in the case of I2h: "*In the laundry room [a guest] turned on the [loud vent used for drying clothes] instead of the light and when we got home, we said: 'Why is*

it running?' and then our guest said he wanted to turn on the light, but he didn't press anything, so he also didn't turn it off again. [He] simply [thought]: I won't touch anything anymore at all."

9 Discussion

The process of getting and using smart home technology yielded interesting challenges and effects that varied in impact. Especially interesting was the fact that the process of planning, integrating, and iterating upon the technology seemed to have a more notable impact on people's lives than the use of the technology itself once installed and working.

Even full automation of control is not a game changer. Surprisingly, despite the cost and effort of instrumenting the home with automation technology, participants pointed out very few direct benefits they derived from the technology or major impacts on their lives or practices. Although some inhabitants (I1, I3, I6) replaced existing manual control of light or shades completely either with control via central touch panel or motion sensors, they still described the effects of the technology as small conveniences rather than substantial support for routines or tasks. People perceived it rather as enhancing their comfort level, but also pointed out that the technology was limited in the help it could provide. PL2w explained the distinction: *"You try to make work a little easier with modern technology. But I still have to do my laundry myself. A laundry chute is there; it carries it in one direction, but besides that..."* Other participants, including professionals, believed that technology does not enable new functions, but incrementally improves what one can already do, as stated by P2: *"It's not like you have a rocket engine in the basement or anything like that. It's comparable to what you had before – just a little smarter and cooler."*

The challenge of planning for unfamiliar technology. It is often difficult to predict what the impact of a new technology will be on one's life or practices; in the case of smart home technology the stakes are particularly high because of the investment involved and the fact that one is not merely purchasing a gadget, but instrumenting one's entire environment. Information about home automation technologies, such as that found on websites, brochures, or manuals, often offers technical details but is less informative about its potential effects on everyday life. At the start of the planning phase, participants reported not understanding potential benefits of technologies (I1, I2h, I3, PL2w) and therefore had difficulties prioritizing those technologies against other needs in the home. Brush et al. found smart home inhabitants "scaling back" installed technologies if they did not provide the expected functionality [5]. We found this pattern as well in our data, but we also found that people were concerned about not being able to anticipate future needs and tried to plan flexible solutions that would allow adding functionality in the future. More specifically, participants without technical backgrounds reported having to rely upon other people's experiences and expertise, and therefore feeling powerless. I5 related a particular incident in which a switchbox installed by electricians proved to be too small, leading to frustration on

her part. However, she felt that she could not have prevented the error, as she did not have technical expertise and therefore had to go along with the decisions of the electricians. Passive users seemed to be skeptical about the general use of home automation technology, as highlighted by PL2w's statement: *"It offers many options, but it's really very complex. The question is: do you really need this?"* They relied on other people's experiences regarding the usefulness of a solution (I2w, I2h, I7). I2: *"We learned from our neighbor's experience regarding the vacuum cleaner [iRobot's Roomba®], and he said it's an amazing device. And that's why we bought it."* Although they did not participate actively in research or planning, they offered input on other decisions that influenced home automation, especially regarding budget decisions as stated by I3w: "*He came to ask when…" I3h: "…for budget planning." [both start laughing] I3w: "Yes, exactly. But besides that – not at all."* Professionals offered another perspective on the challenges of planning. They reported that customers have difficulties understanding the available technology and options (P1, P2, P4, P5). P2 said: *"It just doesn't make sense to people … [that] they need power line switches if they [just] want to have access with their smart phone. They don't see the connection*." P7 illustrated this challenge by contrasting smart homes with more familiar technologies: *"The whole issue of home automation is still so remote. For cars, everyone knows what's possible."*

The challenge of getting high-level expert advice. Participants also reported frustration over being unable to access authoritative and expert advice for high-level decision-making, despite the existence of experts. Professional system integrators (i.e. home automation experts) typically only provided information on the systems that they offered, and other types of home experts, such as electricians and architects, were rarely able or willing to provide information about home automation technology (PL2w, I2w, I2h, I5, P5, P7). I2: *"That was actually the biggest challenge: from whom do I get information about what I really can do, which elements I can buy or use that have what I want…?"* Participants felt they needed an overview of available products in order to identify their needs and choose the right product or combination of products, as stated by I1: *"There was something that I was looking for, but couldn't find… a website that is comprehensive, including all manufacturers, that is unbiased… that presents the various systems, comparing them, showing their advantages and disadvantages. That would have been genius."*

The tension between comfort and control. Although our participants felt that automation resulted in a gain in comfort for some aspects of the home, they also perceived a loss of control with increased automation. I4 talked about the override functions he had created for the home, and PL2w said she feared becoming "a prisoner of the system." Also I2w expressed frustration with automated functionalities *"It bothers me when it turns on the light ten times and I actually don't need it."* Most home technology drivers (I1, I2h, I3h, I5, PL1) expressed indifference to some of the negative effects or constraints resulting from home automation, as illustrated by I3's statement: "*If that happens once or twice a month [the light turning off unexpectedly], then it's at a relative low priority for the 'construction site' [our home]."* Or I2h: *"I just accept that the shades are down and then I just go to the door to look outside."* The difference in roles and responsibilities in smart homes led to issues of control,

such as in one example in which a technology driver (I6h) reconfigured the home in a way that made certain functions unusable to passive users: *"She wanted to turn on the light and then the switch was for the other light because I reassigned it, and then the shutters rolled up on one day, and on another it was a light switch again."*

Experimenting and testing. Home technology drivers often considered the installation and iterating to be hobby, as illustrated by I4's comment*: "In summer I work outside [in the garden] and in the winter it's the visualization and the device automation."* Adult passive users often acted as evaluators (I2w, I3h, I3w, I4, I5) for the drivers' "experiments". *Interviewer: "What turned out to be useless?" I2h: "The motion sensor in the restroom. You [addressing his wife] said: 'No, I don't want that, there needs to be a switch again.' So I added the switch again."* They tended to think about the technology in terms of how it supported their routines and tasks, as exemplified by I3w: *"So when you come home on a winter evening and you've got your hands full of stuff, you open the door but you still have stuff in your hands. So I wanted [the light to turn on automatically] without having to look for the switch."* Technology drivers, in comparison, emphasized the process and implementation. As I1 put it: "*It's not really about [using the technology], but the realization… building this apartment; planning everything, then building it, then making it work. And once everything is done… it's nice to be here, but then new thoughts start: what else could you do?"* Parameterizing, adding new functions, and making it work are perceived as rewarding experiences that provide a sense of achievement, reported explicitly by several of our participants (I1, I4, I6). These findings echo those of previous research that explores the sense of achievement in DIY and repair projects [7, 22].

10 Avenues for Smart Home Research

Our study has uncovered many of the tensions, challenges, and benefits involved in the process of integrating smart home technology into a household. By considering the process in a holistic fashion, we have also identified what we believe to be open areas for smart home research that warrant further exploration.

Design for all phases. Much research on smart homes has focused on providing configuration tools for smart homes, ranging from complex programming environments to simple visual programming tools. These tools are most applicable after all of the necessary technology has been installed and integrated. However, our research has revealed that people need support not only in deciding how to configure their technology, but also in deciding what technology they will need. This phase of planning for a smart home is critical, but support for it is currently fairly minimal. We believe that there are important opportunities for research to support this phase, in terms of presenting people with information about potential technologies, to inform them about their options and help them to make the best decisions to suit their needs. Similar support might also be valuable in the iteration phase, during which households are trying to optimize installed solutions. Informing inhabitants of the outcome of choices and allowing them to explore options more easily might help to

streamline this process, help people to get the most out of the technology, and alleviate the frustrations that people experience with technologies that do not fit well with their lives or that do not work as expected. In architectural planning some dynamic aspects of buildings can be simulated already, such as effects of sunlight or lighting on visual appearances. There are also new ways to plan buildings, such as tools that support building-information modeling[5] and methods to predict building performances in office buildings [15], but usually they are primarily oriented towards experts and not future inhabitants. People in our study considered technologies to be "smart" if they fit their routines and avoid unnecessary work. Thus, early support for the planning process could happen by offering visualizations of current domestic routines, e.g., through collected behavior patterns via sensor data, presenting it to the inhabitants in combination with available automation technology options that can facilitate those routines. While automation experts or consultants are also able to provide support due to their experience with the effects of home automation, we found that our participants had problems getting high-level expert advice.

Supporting hackers and the hacking process. One emerging finding of this study was that the "hacking" of the home was both a primary motivation for installing smart home technology and a perceived major benefit for some household members. Some home technology drivers seemed to want to program the technology as much as they wanted to make use of it. One important direction of smart home research thus far has focused on simplifying the configuration and administration of home technology to make it universally accessible and eliminate the need for "system administrator" knowledge. We agree that this is an important direction to pursue. But our findings also suggest that there may be an important open research direction on providing support to those who want to engage with the technical infrastructure by hacking the home. Providing appropriate tools would not only support the hobby aspect of smart homes but also facilitate experimentation, innovation, and possibly solutions better fitted to the needs of individual households. Although existing products, such as the Arduino[6] prototyping platform and LilyPad[8] support hardware hacking, this avenue of research still presents design challenges in terms of how to support the hacking process specifically within the context of homes. Dixon et al. approach facilitating software prototyping in automated homes by suggesting a common operating system for homes [12] that could help to overcome the problem of sharing source code within the hacking communities across very heterogeneous installations. But as we further identified problems that especially concern other household members, indirect support of the hacking process could include minimizing inconvenience for effected persons, avoiding disruption of their existing routines, and communicating process information to them, e.g., by providing cues about whether the house is currently in a "testing mode" and that it might behave unexpectedly rather than allowing a chance that they might doubt own actions and lose trust in the reactions of their own home.

Exploring support for passive users. Although the passive users in our participant households did not engage directly in the planning or configuration of home

[5] http://usa.autodesk.com/building-information-modeling/
[6] http://www.arduino.cc

automation technology, we found that their needs and practices still had an influence on its design and use. The passive users were asked to give approval for certain decisions and provided feedback towards optimizing the configuration of technologies to suit the household. Although they wanted to give others in the household freedom to "hack", it was apparent that they still had some investment in ensuring that the technologies worked as expected and needed. We therefore feel that there is an important open avenue of research to be explored on how other members of the household can shape and influence the technologies without investing significant time or effort, and possibly while avoiding the need for direct interaction with the system. For example, it may be worthwhile to consider how household members can provide feedback to systems or to technology drivers in novel and implicit ways, or perhaps ways to support a more collaborative evolution of the home technology.

By taking a broad approach to studying real-world manifestations of smart home technology, we have uncovered practices and implications that go beyond the interactions of technology enthusiasts with home technology to include a variety of stakeholders and extended process of planning and development. In addition to shedding light on the impacts of these technologies on homes and everyday life, we believe they point to important new areas for the research community to explore.

Acknowledgements

We would like to thank Gunnar Harboe, Christian Remy, Frank Bentley, and Khai Truong for their help on this paper. Thanks to Peter Sperlich for interesting insights. Special thanks to Loxone, nomos system, geSys, myHomeAutomation.de, Zenon Schymiczek, and all other participants for their time and effort.

References

1. Aipperspach, R., Hooker, B., Woodruff, A.: The heterogeneous home. In Ubicomp (2008)
2. Allouch, S. B., Van Dijk, J.A.G.M., Peters, O.: The Acceptance of Domestic Ambient Intelligence Appliances by Prospective Users. In Pervasive (2009)
3. Ballegaard, S.A., Bunde-Pedersen, J., Bardram, J.E.: Where to, Roberta?: reflecting on the role of technology in assisted living. In NordiCHI (2006)
4. Bell, G.,Kaye, J.: Designing Technology for Domestic Spaces: A Kitchen Manifesto. Gastronomica 2, 2 (2002), 46-62.
5. Bernheim Brush, A.J., Lee, B., Mahajan, R., Agarwal, S., Saroiu, S., Dixon, C.: Home automation in the wild: challenges and opportunities. In ACM CHI (2011)
6. Beyer, H., Holtzblatt, K., Contextual Design: Defining Customer-Centered Systems, Morgan Kaufmann Publishers Inc., San Francisco (1997)
7. Buechley, L., Paulos, E., Rosner, D., Williams, A. Ed.: DIY for CHI: Methods, Communities, and Values of Reuse and Customization. Workshop held at ACM CHI (2009)
8. Buechley, L., Eisenberg, M., Catchen, J., Crockett, A.: The LilyPad Arduino: Using Computational Textiles to Investigate Engagement, Aesthetics, and Diversity in Computer Science Education. In ACM CHI (2008)

9. Chetty, M., Sung, J., Grinter, R.E.: How Smart Homes Learn: The Evolution of the Networked Home and Household. In UbiComp (2007)
10. Crabtree, A., Rodden, T.: Domestic Routines and Design for the Home. In CSCW (2004)
11. Davidoff, S., Lee, M.K., Yiu, C., Zimmerman, J., Dey, A.K.: Principles of Smart Home Control. In UbiComp (2006)
12. Dixon, C., Mahajan, R., Agarwal, S., Brush, A.J., Lee, B., Saroiu, S., Bahl, V.: The home needs an operating system (and an app store). In HotNets (2010)
13. Edwards, W., Grinter, R.: At home with ubiquitous computing: Seven challenges. In UbiComp (2001)
14. Elliot, K., Neustaedter, C., Greenberg, S.: Time, Ownership and Awareness: The Value of Contextual Locations in the Home. In UbiComp (2005)
15. Goldstein, R., Tessier, A., Khan, A.: Customizing the Behavior of Interacting Occupants using Personas. In SimBuild (2010)
16. Greenberg, S., Neustaedter, C., Elliot, K.: Awareness in the Home: The Nuances of Relationships, Domestic Coordination and Communication. In Awareness Systems (2009)
17. Hughes, J.A., O'Brien, J., Rodden, T., Rouncefield, M., Viller, S.: Patterns of Home Life: Informing Design For Domestic Environments. In Personal and Ubiquitous Computing (2000)
18. Humble, J., Crabtree, A., Hemmings, T., Åkesson, K., Koleva, B., Rodden, T., Hansson, P.: "Playing with the Bits" User-Configuration of Ubiquitous Domestic Environments. In UbiComp (2003)
19. Intille, S.S.: Designing a home of the future, In Pervasive Comp., vol. April-June, (2002)
20. Kane, S.K., Wobbrock, J.O., Ladner, R.E.: Usable gestures for blind people: Understanding preference and performance. In ACM CHI (2011)
21. Kietz, J., Patel, S., Jones, B., Price, E., Mynatt, E., Abowd, A. The Georgia Tech Aware Home. In ACM CHI Extended Abstracts (2008)
22. Maestri, L., Wakkary, R.: Understanding repair as a creative process of everyday design. In C&C (2011)
23. Poole, E.S., Chetty, M., Grinter, R.E., Edwards, W.K.: More than meets the eye: transforming the user experience of home network management. In DIS (2008)
24. Randall, D.: Living Inside a Smart Home: A Case Study. In Harper, R. (ed). Inside the Smart Home, Springer-Verlag, London. (2003)
25. Röcker, C., Janse, M., Portolan, N., Streitz, N. A.: User Requirements for Intelligent Home Environments: A Scenario-Driven Approach and Empirical Cross-Cultural Study. In ACM sOc-EUSAI'05 (2005)
26. Rodden, T., Crabtree, A., Hemmings, T., Koleva, B., Humble, J., Åkesson, K-P., Hansson, P.: Configuring the Ubiquitous Home, In Proceedings of Designing Cooperative Systems (2004)
27. Rode, J.A., Toye, E.F., Blackwell, A.F.: The domestic economy: a broader unit of analysis for end user programming. In ACM CHI Extended Abstracts (2005)
28. Rode, J.A., Toye, E.F., Blackwell, A.F.: The fuzzy felt ethnography-understanding the programming patterns of domestic appliances. Personal and Ubiquitous Computing (2004)
29. Taylor, A. S., Harper, R., Swan, L., Izadi, S., Sellen, A., Perry, M.: Homes that make us smart. In Personal and Ubiquitous Computing (2006)
30. Tolmie, P., Pycock, J., Diggins, T., MacLean, A., Karsenty, A.: 'Towards the Unremarkable Computer: Making Technology at Home in Domestic Routines', In Harper, R. (ed). Inside the Smart Home, Springer-Verlag, London. (2003)
31. Truong, K.N., Huang, E.M., Abowd, G.D.: CAMP: A Magnetic Poetry Interface for End-User Programming of Capture Applications for the Home. In UbiComp (2004)
32. Wilkowska, W., Ziefle, M.: User diversity as a challenge for the integration of medical technology into future home environments. In Human-Centred Design of eHealth Technologies.(2011)
33. Woodruff, A., Augustin, S., Foucault, B.: Sabbath Day Home Automation: "It's Like Mixing Technology and Religion.".In ACM CHI (2007).